Belowground aboveground interactions

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I. Structure of soil food webs
II. Carbon flux into decomposer system
III. Below - aboveground linkages
   (A) The plant pathway
   (B) The generalist predator pathway
IV. Summary
The local diversity is exceptionally high: in temperate forests > 2000 animal species („the poor man’s tropical rainforest“)

High diversity despite low diversity of primary producers
… and form complex food webs

Detritus based subsystem

➔ Detritus (litter) as basal resource
➔ Discrete trophic levels; few trophic levels
➔ Taxonomic groups as trophic species

Plant based subsystem

Top predators

Schaefer & Scheu 1996
I. 
Trophic niches 
and 
food web structure
Analysis of trophic structure using stable isotopes

$^{15}$N in aquatic food webs

I. Trophic niches and food web structure

Wada et al. 1991

Enrichment in $^{15}$N per trophic level
Stable isotopes and trophic niches

„Fungal feeders“: Oribatida

I. Trophic niches and food web structure

→ Understanding trophic niches of soil animal species
→ Reconstruct the trophic structure of soil food webs

Schneider et al. 2004
Phospholipids (PLFAs) from dietary species are incorporated into neutral lipids (NLFAs) of consumers and used as biomarkers.

- Absolute markers are not synthesized in consumer.
- Relative markers are enriched in consumer if present in diet.
Lipid analysis

Tropical soil fauna (rainforest, rubber and oil palm plantations)

Quantifying the contribution of major basal resources for soil animal nutrition

Understanding the channelling of energy to higher trophic levels
Molecular gut content analysis I

Tracing prey DNA in the gut of predators by using species specific primers (COI and/or 18S rDNA)

Collembola as prey of centipede predators

Screening predator populations in the field for prey taxa
Opening up food web links
Molecular gut content analysis II

Tracing nematode prey DNA in the gut of „detritivores“

Most „detritivore“ microarthropods also feed on nematodes

Trophic generalism and omnivory very widespread

Heidemann et al. 2014
Linking food web structure and body size:
Energy channelling and quantifying ecosystem functions

- Understanding the channelling of energy through soil food webs
- Quantifying ecosystem functions: decomposition, herbivory, predation

Potapov et al. 2019
II. Carbon flux into decomposer system
The traditional view of decomposer systems

- Separate above- and belowground food webs
- Belowground food web based on aboveground litter input
- Detritivores linked to plants by mineralization of nutrients

Nutrients

Herbivores

Predators

Shoot

Litter

Detritivores

Predators

5-10% of NPP

<5% of NPP

90-95% of NPP!!
Analysing the trophic structure of soil food-webs

Stable isotope signatures after 5 months of maize plantation

Collembola acquire much of their C resources via roots

Fast C turnover in Collembola

Albers et al. 2006
Swiss Canopy Crane Webface experiment

**Methods:**

# Release of CO$_2$ depleted in $^{13}$C, -30 vs. -8 δ (increasing CO$_2$ concentration to 530 ppm)

# Exchange of litter labelled vs. unlabelled

Pollierer et al. 2007
Trophic structure and carbon flux in mature forests
Soil fauna signatures after 17 months

Pollierer et al. 2007

➔ Root C input much more important than litter C input
Carbon flux and food web of terrestrial systems

- Root feeder channel
- Mycorrhiza channel
- Bacteria channel
- Saprotrophic fungi channel

Predators

Root feeding "decomposers"
Fungal feeders
Bacterial feeders
Litter chewers
Saprotrophic fungi

Mycorrhiza
Bacteria

Root carbon
Plant residues

⇒ "Decomposer“ food web relies substantially on currently fixed plant carbon
III.

Below - aboveground linkages:

A - The plant pathway
Integration of below- and aboveground system

The plant pathway

- Positive interaction
- Negative interaction
- Energy flow

Indirect interactions via
- Changing soil structure
- **Mineralization of nutrients**
- Grazing on rhizosphere bacteria
- Grazing on rhizosphere fungi
- Dispersal of microorganisms antagonistic to root pathogens

Direct interactions via
- Root feeding
- Transposal of plant seeds

Modifying aboveground interactions by changing plant growth, plant chemistry and plant community composition
Indirect trophic interactions in the rhizosphere
Grazing on rhizosphere fungi

- Increase in nutrient mineralization via feeding on fungi …
- but also the reverse …
Indirect trophic interactions in the rhizosphere
Earthworm – Collembola interactions
Plant nitrogen uptake

➔ Additive increase in tissue $^{15}$N concentrations
➔ Complementary effects on plant growth and $^{15}$N uptake!

Partsch et al. 2006
Indirect trophic interactions in the rhizosphere
Collembola and aboveground herbivores
Aphids on winter wheat

Collembola reduce aphid reproduction and may contribute to biological pest control

Schütz et al. 2008
Signalling view of detritivore – plant interactions

Herbivores, pathogens

Interaction between plants and detritivores via mutual perception of signal compounds

Root signals

Detritivore signals

III. Below - aboveground linkages: A - The plant pathway
Gene expression patterns in gnotobiotic systems

Effects of Collembola on gene expression in *Arabidopsis thaliana*

The model system

Methods:
# Axenic system with sand + litter (\(^{15}\)N labelled)
# Custom made micro-array covering 1054 gene-specific target sequences: stress response, signalling and biosynthesis of secondary metabolites

Endlweber et al. 2011
Effects of Collembola on gene expression in A. thaliana

Expression patterns in shoots and roots

Number of genes regulated at day 6 in roots and shoots

- 54 genes; root
- 27 genes; root
- 4 genes; shoot and root
- 29 genes; shoot
- 31 genes; shoot
- 6 unregulated

Functional groups of genes regulated in roots at day 6

- Auxin response & biosynthesis 16%
- Other hormone-related responses 5%
- Signaling 4%
- WRKY transcription factors 7%
- Stress response and defensive compounds 10%
- Phenylpropanoid/Flavonoid metabolism 5%
- Secondary Metabolism CYP; UGT; GST 39%
- Aquaporins 7%
- Transport 3%
- Other metabolism 4%

➔ Strong gene expression response due to presence of Collembola
➔ Induction of genes regulating root growth
➔ Induction of defence genes, in particular in shoots!
➔ Response resembles that of root herbivores!

Endlweber et al. 2011
Gene expression patterns in trees

Transcriptional response of *Quercus robur* to Collembola

The model system

Methods:

# Axenic system with sterilized soil inoculated with mycorrhiza (*Piloderma croceum*)

# Transcriptomics
Effects of Collembola on transcriptional response in *Q. robur*

Expression patterns in leaves during shoot- and root-flush

<table>
<thead>
<tr>
<th>Differential gene expression</th>
<th>Shoot flush (SF)</th>
<th>Root flush (RF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of contigs</td>
<td>467</td>
<td>120</td>
</tr>
<tr>
<td>of which up-regulated</td>
<td>410</td>
<td>65</td>
</tr>
<tr>
<td>of which down-regulated</td>
<td>57</td>
<td>55</td>
</tr>
</tbody>
</table>

Including Gene Ontology (GO) terms for

- **primary metabolism**: e.g., cell proliferation, regulation of cell cycle
- **defence related contigs**: e.g., defence response of insects, flavonoid biosynthesis, salycilic acid mediated pathway, jasmonic acid mediated pathway

- **Strong gene expression response due to presence of Collembola**
  - Increase in GO terms related to primary growth during SF
  - Increase in GO terms related to physical fortification during RF
  - Increase in GO terms related to plant defence
  - Increasing plant growth and fortification as well as priming against herbivore attack

Graf et al., in revision
III.

Below - aboveground linkages:

B - The generalist predator pathway
Feedbacks to aboveground system via generalist predators

The detritivore – generalist predator – herbivore pathway

- Positive interaction
- Negative interaction

energy flow

Below-ground energy subsidy

Generalist predators

Herbivores

Plants

Microbi/detritivores

Detritus

Scheu 2001

➔ Changing herbivore control by energy subsidy from decomposer system

➔ „Dual subsystem omnivory“
Feedbacks to aboveground system via generalist predators
Addition of detrital resources (maize litter; 5 months)

- Increase in Collembola density by a factor of 3.9
- Increase in density of cursorial spiders by a factor of 2.9

Strong link between detritivores and generalist predators

Oelbermann & Scheu 2008
Detritivores as energy subsidy for generalist predators

Arable systems: Effects on aphid (*Sitobion avenae*) control

- Effective control of aphids by generalist predators
- Fostering the detrital system by mulching strengthens the control of aphids by generalist predators

Von Berg et al. 2010
The detritivore – generalist predator – herbivore pathway

Moisture driven prey switching

III. Below aboveground linkages: B - The generalist predator pathway

- Sustaining of predator populations by detritivore prey
- Switching to herbivore prey during vegetation period
Summary

➢ New tools/methods allow unprecedented progress in understanding the structure and functioning of soil food webs
  ➢ Roots of major importance for fuelling decomposer food web
  ➢ Detritivores affect plant growth, plant gene expression, and the susceptibility of plants to herbivore attack
  ➢ Complementary effects of detritivore functional groups
  ➢ Detritivores may strengthen the control of aboveground herbivores via generalist predators

➔ For developing more sustainable agricultural systems soil animal communities need considerably more attention
Thanks to ...

... and you for listening!
Lipid analysis
Dietary rooting: neutral lipids in Collembola

Ruess et al. 2005

Neutral lipid analysis allows refinement of trophic niches
> Contribution of bacteria, fungi, animals and plants to diet
> Channelling of basal resources through food web
Indirect trophic interactions in the rhizosphere

Earthworm – Collembola interactions

Experimental setup

Variables studied:

# Plant species number (1, 2, 4, 8)
# Plant functional group number (1, 2, 3)
# Plant functional group identity (grass, legume, herb)
# Earthworms (with/without *Lumbricus terrestris* + *Aporrectodea caliginosa*)
# Collembola (with/without *Heteromurus nitidus* + *Folsomia candida* + *Protaphorura fimata*)

⇒ 256 microcosms
Indirect trophic interactions in the rhizosphere
Earthworm – Collembola interactions
Plant growth

➔ Additive increase in plant biomass
➔ Maximum plant biomass in combined treatment
➔ Strong changes in root biomass; reduced by earthworms and Collembola but not in combined treatment
➔ Interactive effects of decomposers on plant performance
➔ Strong changes in plant resource allocation pattern

Partsch et al. 2006
Collembola decrease root diameter and volume, but increase root length and number of root tips

Indirect trophic interactions in the rhizosphere
Collembola and root morphology

Epilobium adnatum & Cirsium arvense

Endlweber & Scheu 2006